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Effect of polymer coating on the behavior of an electro–rheological fluid in slit flow

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Abstract

Electro–rheological (ER) effect is the term applied to the rapid and reversible changes in rheological properties of certain suspensions or solutions under the application of an electric field. In this study, the dependence of ER-effects of an ER-fluid in rotational as well as in slit flow on electric field strength, field frequency, shear rate and volumetric flow rate was quantified using the Casson model. In addition, the effects of coating the electrodes with a polymer mesh (trevira) on the behavior of an ER-fluid in slit flow were investigated. The results showed that with the trevira mesh on the surface of the electrodes, the ER-fluid demonstrated greater increase in the pressure drop upon the application of both AC- and DC- field. Compared to the uncoated electrodes, the relative ER-effects for the electrodes with the trevira mesh were 1.12–4.23 times larger. On the other hand, the ER-effect of the ER-fluid used can be increased by installation of trevira mesh without increasing the current levels under constant electric field strength.

1. Introduction

The electro–rheological (ER) phenomenon is related to changes in rheological properties of the certain suspensions or solutions upon the application of electric field. The electro–rheological effect results in an abrupt increase in resistance to flow and sometimes shows transition from the fluid state to weak solid behavior. The fluid showing this kind of a large, reversible change in viscosity with the electric field is called the electro–rheological fluids. ER-fluids constitute an exciting field of study especially since they seem to offer an unlimited potential for practical applications.

The possibilities for employing the ER phenomenon in practical applications have long been recognized, e.g. in clutches [1], shock absorbers, hydraulic valves [2], vibration dampers, motor bearings [3],etc. The principle attraction of using ER-fluids in these devices is their fast response time. This feature makes possible feedback control systems for robotics and automotive applications, which are greatly improved over existing models. Further advantages of ER-fluid devices would be to reduce the engine load, noise, structural requirements of the accessories, etc. However, not many ER devices have been commercialized because of a number of problems that must be solved: their apparent viscosity is not high enough; they have a limited working temperature range; they present problems of suspension stability against sedimentation, and the prohibitive power requirements to achieve a useful enhancement in viscosity [4].

The attempts of the enhancement of the ER-effect go into two directions; the first one is the improvement of the ER-fluids, which received high attentions (e.g. [5,6]). The alternative method for the improvement of the ER-effect is through the change of the electrode pattern, which has not received much attention in the literature. Monkman [7] attached to the electrode surfaces one or more layers of a cotton fabric. In the best case, increases in the measured torque by a factor of 2 (relative to the uncoated electrodes) were observed.

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Nomenclature

c_1, c_2, c_1', c_2'	constants
E	electric field strength
f	electric field frequency
$F_{\Delta p}$	relative ER-effect in slit flow
$F_{\Delta \tau}$	relative ER-effect in viscometer
H	channel height
I	electric current
j	current density
l	length for the pressure drop measurement
Δp	pressure drop
Δp_E	pressure drop with an applied electric field
$\Delta p_{E=0}$	pressure drop without an electric field
Q	volumetric flow rate
U	electric voltage
$\beta_0, \beta_1, \beta_2$	fit parameters for Casson-like-model
η_c	Casson viscosity
$\dot{\gamma}$	shear rate
μ	Newtonian viscosity
τ	shear stress
τ_c	yield stress
$\tau_{E=0}$	shear stress without an electric field
$\tau_{E>0}$	shear stress with an applied electric field
τ_w	wall shear stress

The dynamically tunable capability of a sandwich beam with embedded electro–rheological material has been proven to be a viable tool for the vibration control of structures. In order to enhance the controllable dynamic characteristics of the sandwich beam, Choi et al. [8] studied several specimens with different surface modifications on the electrode surfaces. They showed that the specimen with electrode surfaces roughened by sandpaper demonstrated a greater ER effect than its counterpart with original surfaces. On the other hand, the specimens with attached circular or rectangular polyvinyl patches on the electrode surfaces did not significantly show a difference from the original specimen.

In the work of Katsikopoulos and Zukoski [9], the effects of electrode morphology on the electro–rheological response in AC-fields were studied. The electrodes were machined with axial grooves and ridges. This induced changes in the local electric field and resulted in a highly localized structure. The achieved increase in stress was around twofold, when compared to the smooth electrode behavior.

Using experimental ER-fluids, Abu-Jdayil and Brunn [10,11] conjectured that there could be cases in which the applying of a non-uniform electric field should be superior to a uniform one. The effects of non-uniform electric field as well as the effects of electrode morphology on the slit flow (laminar flow between two parallel plates) of an electro–rheological fluid have been studied. The measurements in slit flow (with inhomogeneous electric and flow field) show a greater ER-effect in comparison to the case of smooth electrodes. As a matter of fact the addition of a punched PVC-foil to the electrodes led to an increase of the ER-effect (in comparison to the uncoated electrodes). Altering of the electrode geometry in a slit flow an enhancement in the ER-effect was predicted. Under AC conditions, the ER-effect with oblique and corrugated electrodes was greater in comparison to the case of smooth electrodes at the same electric field strength and pressure drop.

Slit flow of an electro–rheological fluid in an AC-field with and without obstruction was investigated by Wunderlich and Brunn [12]. Non-viscometric flow conditions were attained either by keeping the lengths of electrodes short or by obstructing the flow via protruding electrodes. These latter conditions were somewhat beneficial at low volume flow rates.

In the study of Lee and Jwo [13], the dynamic characteristics of the ER material under the influence of the electric field established between electrodes with grooved surfaces were investigated experimentally. The measured shear modulus of the ER material using a parallel-plate fixture showed that, by modifying the electrode surfaces with parallel machined grooves, there was a 30% greater increment in the modulus at the applied electric field strength of 1.3 kV/mm compared to its counterpart without surface modification. However, an associated increment in the electrical power supply is demanded.

The influence of inhomogeneous flow conditions besides the influence of the inhomogeneity of the electric field on the behavior of an ER-fluid in a clutch mechanism were also studied [14]. A set of smooth plates and three further sets of plates with different surface finishes were used in this investigation. Relative to the smooth plates, an increase in the relative ER-effect resulted when the oblique plates were used in an AC and DC-field. This improvement in ER-effect seems to be tied to the increase in local field strength at the thick rim of the oblique plate. The addition of metal sheets to the smooth plates of the clutch provided a small increase in ER-effect under AC conditions. But in a DC-field, the increase in ER-effect relative to that for smooth plates was rather pronounced, but so was the increase in electric current.

In an attempt to enhance the electric response of electro–rheological fluids under DC electric field conditions, the influence of the electrode surface morphology has been studied by Hanaoka et al. [15], using a rheometer in which the electrode surface was covered with a thin metallic net. The aggregation of particles and the ER responses in fluids used revealed the effect of local changes in the electric field on the metallic net surface. It was shown that a metallic net on the electrode surface is effective for further promoting the rheological response of an ER-fluid. The responses